

# RHIC PRESSURE RISE\*

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## Abstract

Beam induced pressure rise remains an intensity limit at RHIC for both heavy ion and polarized proton operations. The pressure rises at beam injection, transition, and rebucketing are discussed, where the beam rebucketing pressure rise is probably of most concern for upcoming runs. Counter measures and results of beam studies are presented.

## INTRODUCTION

In RHIC Run-2 (FY01-02), the beam injection pressure rise caused vacuum valve closures and beam aborts, limiting the beam intensity [1,2]

In d-Au (deuteron-gold) operations of RHIC Run-3 (FY03), the transition pressure rise caused experiment background problems, limiting the beam intensity [1-3]. This pressure rise is related to total beam intensity. In the d-Au run, the beam intensity reached  $140 \times 10^9$  gold ions (charge equivalent), the transition pressure rise was of serious concern at above  $120 \times 10^9$ .

The Au-Au operation in Run-4 (FY04) was with the total beam intensity less than  $105 \times 10^9$  gold ions, nevertheless, the pressure rise at the beam rebucketing (bunches are recaptured by the storage cavities) became a new limit, affecting the experiment background [4]. The increased storage RF voltage from 2.5 MV to up to 4.8 MV was probably a cause of this problem.

All these pressure rises are of concern, however, it is foreseeable that the problem of rebucketing pressure rise is most relevant in the RHIC Run-5 and beyond.

For counter measures, NEG (non-evaporable getter) coated pipes were installed in the RHIC ring for testing. The evaluation was positive in general, however, questions exist.

The ion desorption has been extensively studied in RHIC for two reasons. Firstly, a possible large ion desorption seems to be directly responsible for some types of pressure rise. Secondly, ample production of secondary positive ions in beam scraping may have caused the development of electron multipacting, in spite of very long bunch spacing from 108 ns to 432 ns.

Many other studies related to counter measures have been performed in the past year. Among them are beam scrubbing, beam gap and beam pattern effects, solenoid effects, and beam momentum spread effects at transition [5-7].

A comprehensive strategy has been proved useful in RHIC operations for addressing the pressure rise

concerns. In general, it is better to extend the bunch spacing and to raise bunch intensity, since the reduction of electron multipacting is more than linearly proportional to the bunch spacing. Moreover, for equal luminosity, fewer bunches with higher bunch intensity actually requires lower total beam intensity.

## PRESSURE RISE OBSERVATIONS

Injection pressure rise has been diagnosed to be mainly due to electron multipacting. The associated threshold was increased in later runs by extensive chamber baking and other improvements. The injection pressure rise is now routinely observed in RHIC operations for high intensity beams, nevertheless, with 56 or fewer bunches, this pressure rise is presently not a limiting factor.

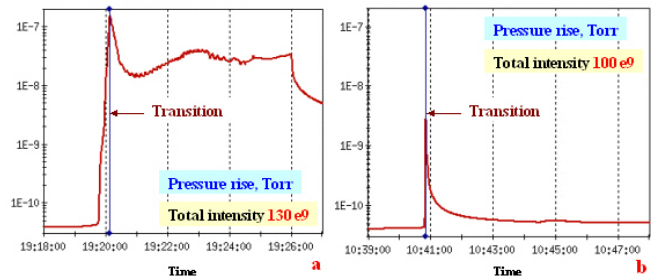


Figure 1: Typical transition pressure rise in the d-Au run. The left figure is with the total beam intensity of  $130 \times 10^9$  gold ions equivalent, and right figure is with  $100 \times 10^9$ . At the higher beam intensity, the high pressure lasted much longer.

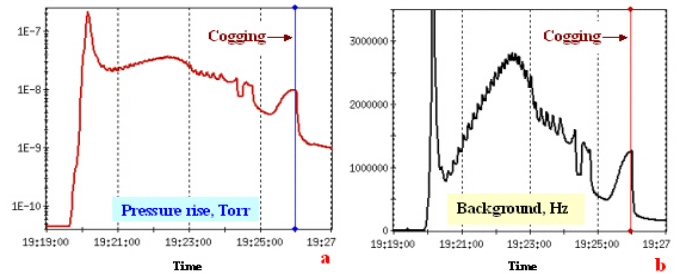


Figure 2: Transition pressure rise at high beam intensity caused experiment background problems. The pressure was reduced after beam cogging, but the corresponding singles rate was still 200 kHz, much higher than the coincident rate of 7 kHz.

Transition pressure rise was barely observed in Run-2, since the total beam intensity then was less than  $80 \times 10^9$

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gold ions. In Run-3, when the d-Au total beam intensity increased above  $120 \times 10^9$  gold ions (charge equivalent), the pressure rise at interaction regions reached  $5 \times 10^{-7}$  Torr. As seen in the typical transition pressure rises shown in Fig.1, higher beam intensities not only caused higher peak pressures, but also the high pressure lasted for a longer time after the transition. This high pressure sometimes caused very large singles rate (background) for the detectors due to beam gas collisions. Fig.2 shows that the singles rates were caused by the high pressure in an interaction region. It took up to 10 hours for this pressure to reduce to an acceptable level. In the d-Au run, the background problem was mitigated by replacing the 112-bunch mode with 56-bunch mode, which requires less total beam intensity for the same luminosity.

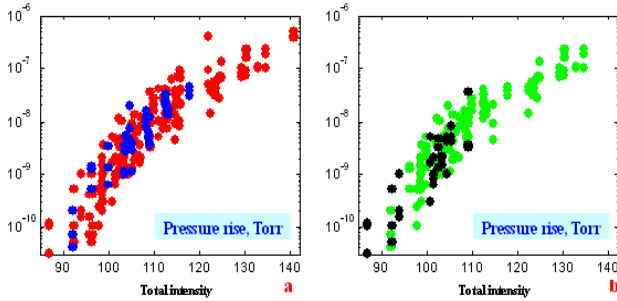


Figure 3: Transition pressure rise at 3 interaction regions in the d-Au run. Left side, red: 112-bunch mode, blue: 56-bunch mode. Right side, green: high deuteron intensity, low gold intensity. Black is vice versa.

In Fig.3a, it is shown that the transition pressure rise is insensitive to bunch spacing, indicating that electron cloud is not a dominant mechanism. In Fig.3b, it is shown that the pressure rise is insensitive to ion species. Since the gold ion gas ionization cross section is about 79 times larger than the deuteron's, this indicates that the gas ion desorption (ISR type) is not a dominant mechanism. It is suspected that the transition pressure rise is caused by halo scraping due to the large beam momentum spread at transition. Nevertheless, the fact that the transition pressure rise is quasi-exponentially proportional to total beam intensity cannot yet be explained.

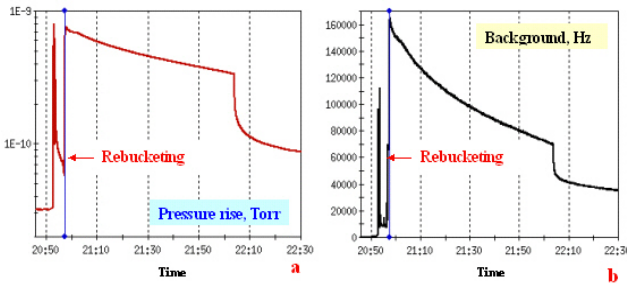


Figure 4: Rebucketing pressure rise and experiment background. Bunch length is shortened from 10 ns to 5 ns at rebucketing, which may have excited electron multipacting. The later sudden dramatic pressure reduction may be caused by the cease of multipacting.

In Run-4, the total beam intensity was no more than  $105 \times 10^9$  gold ions, and the transition pressure rise induced background problem was not expected to be serious. However, improvements in the beam rebucketing, led to 20% increase of the beam momentum spread and higher than 5 A of peak current for a bunch intensity of  $10^9$  gold ions, caused pressure rises which affected the experiment background, and hence limited beam intensity. Several peculiar features indicate that this pressure rise is due to electron multipacting. For example, increasing the average bunch spacing helped to mitigate the problem. In the later run, a 45-bunch mode was used to improve the background problem. Fig.4 shows the rebucketing pressure rise and background at the experiment PHOBOS, which was the tightest limit in Run-4 [8,9].

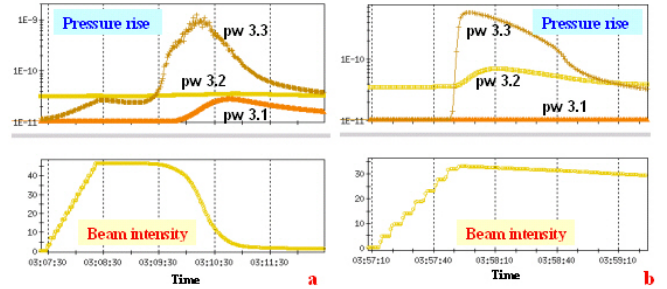


Figure 5: Evaluating NEG coating by observing pressure rise caused by beam loss, on the left, and by exciting electron cloud, on the right. The pressure rise at the gauge pw 3.2 is low in both cases, because of the NEG pipes. The location of pw 3.2 usually has the highest pressure rise.

## COUNTER MEASURES AND BEAM STUDIES

A total of 60 meters of NEG coated pipes were installed in 6 locations in RHIC to evaluate pumping, secondary electron yield reduction, and possible electron and ion desorption reductions. Beam loss was intentionally created in the NEG pipe vicinity to observe pressure rise. A few bunches of beam were dumped at the NEG pipe and nearby steel surfaces to compare ion desorption rates. Electron multipacting was also excited for evaluation. In Fig.5a, a beam loss induced pressure rise is shown, and in Fig.5b, a pressure rise due to electron cloud is shown. The pressure rise at the middle of a 34 meters long straight section is usually the highest, but in both cases it is low because of the NEG pipes installed in the vicinity.

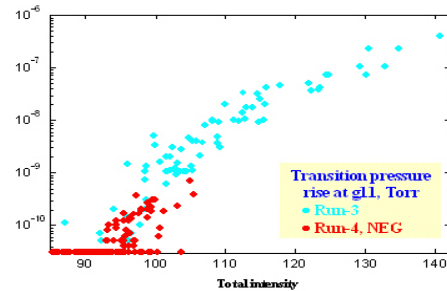


Figure 6: Transition pressure rise at g11 (red for Run-4), where a 5 meter long NEG coated pipe was installed on one side. To compare, the g11 transition pressure rise in d-Au operation of Run-3 is also shown, in cyan.

In Fig.6, the transition pressure rise in the interaction region at section 11, where a 5 meter NEG pipe is on one side of the gauge, is shown against the pressure rise history of Run-3. It seems that the NEG pipe helped, especially at high beam intensities.

During beam studies and operations, the pressures in the vicinity of NEG pipes were always low, however, the contribution of the pumping cannot be identified and separated from other mechanisms. In the proton run, high pressure rise at a NEG pipe location during an electron multipacting event was observed, which needs investigation.

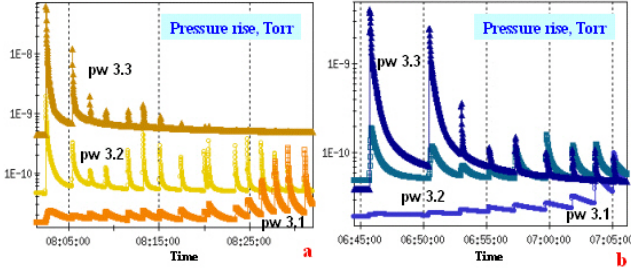


Figure 7: Ion desorption measurement. About  $3 \times 10^9$  gold ions at 8.9 GeV/u dumped in two straight sections with incident angles 1 to 3 mrad. On left sides of each test, at about 3.2 mrad, ion desorption rates are  $10^6$  to  $10^7$ .

The ion desorption effect was studied by creating beam scraping at the warm straight sections, either using a dipole to control the local beam loss, or simply using corrector dipoles to steer and dump a few bunches of beam at different locations. In both ways, the ion desorption rate of incident angles from 1 to 3 mrad is about  $2 \times 10^4$  molecules. Nevertheless, in both studies, some irregular cases were found showing much higher desorption rates. For instance, in Fig.7, a desorption rate up to  $1.3 \times 10^7$  is shown. Comparable test results were also obtained with proton beams. It is suspected that in these incidents a part of the beam particles may actually be executing halo-like scraping at much smaller angles, giving rise to the high yield. This speculation is consistent with studies using the collimator scraper. Normally, little or no pressure rise is produced in the beam collimation, but sometimes very high desorption rates are observed, as shown in Fig.8.

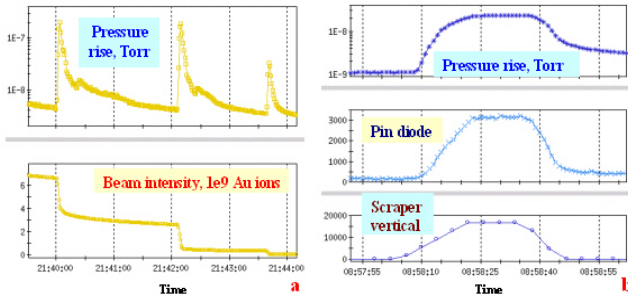


Figure 8: Left, gold beam collimation at 8.9 GeV/u. In all 3 incidents, ion desorption rates are  $\sim 1.5 \times 10^7$ . Right, vertical scraping caused pressure rise at 100 GeV/u. The deuteron ion desorption rate is larger than  $10^7$ .

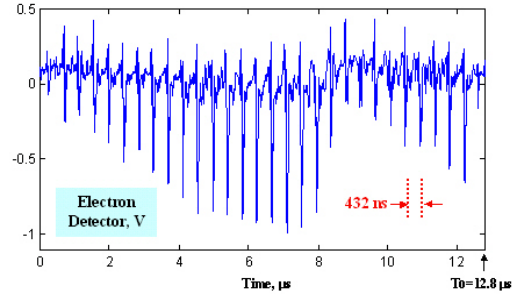


Figure 9: Electron multipacting of 28 bunches with  $1.7 \times 10^{11}$  protons per bunch, bunch spacing is 432 ns. Two beams with 10 ns bunch length meet at the location of the electron detector, with offset of 3 ns in time.

High ion desorption rate may imply ample production of positive ions in halo scraping, which helps to explain the RHIC electron multipacting with large bunch spacing. In Fig.9, a strong electron multipacting at a straight section is shown, the bunch spacing is 432 ns. This is probably the largest bunch spacing for which multipacting is observed.

In a dedicated study, non-trivial beam scrubbing effects were observed in most of the single beam straight sections. A feasibility of beam scrubbing to allow higher beam intensities has been demonstrated for RHIC [5].

The effect of distributions of bunches along the circumference that minimize the electron cloud effect has also been demonstrated and actually used in operation [6]. In Fig.10, the Run-4 Au-Au operations history is shown of using 45-bunch to 68-bunch modes to optimize the luminosity, by allowing largest beam intensity with tolerable PHOBOS pressure rise and background.

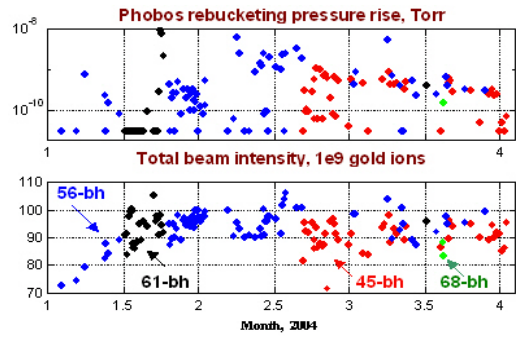


Figure 10: 143 high intensity fills of a total 274 fills of Run-4 Au-Au run. Bunch mode was chosen according to injector and rebucketing pressure rise conditions. 45-bunch mode is used for higher luminosity and lower background.

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